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ABRASION EROSION RESISTANCE OF VARIOUS REPAIRING MORTARS

by

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ABSTRACT

Slurry erosion tests were made in order to determine the factors influencing the abrasion-erosion resistance of some mortars. The apparatus used produced a slurry jet which impinged the surface of mortar specimens with an incidence angle of 45° and a velocity of 18.5 m/s. The results showed that the epoxy mortars were the most erosion wear resistant compared with grouts and polymer mortars. The wear of mortars is controlled by the wear of the binder (epoxy or cement) and a strong relation exists between the erosion resistance of the mortar and the absence of microporosity in the binder. The results also suggest to minimize the exposed areas of the binder by using sand particles with a wide size distribution.

1. INTRODUCTION

The degradation of concrete hydraulic structures is a slow process and is influenced by many factors. One of the most important is erosion, a fairly prevalent problem and an issue of serious concern to electrical utilities, especially those operating old concrete hydraulic structures. The damage it causes falls into three categories [1]:

- Abrasion: wearing away of the concrete surface due to the action of flowing water and the fine and coarse particles of sand, silt, gravel and other solids that it carries. The resulting surface is smoother than those damaged by cavitation erosion.

- Cavitation: a pitting of the surface around hard coarse aggregate particles due to vapor bubbles forming in low-pressure areas in flowing water and collapsing as they enter areas of high pressure. The cavities produced can be up to 6 m deep [2].

- Chemical action: etching of the concrete surface by the flow of fresh water over it. This problem is not very common in hydraulic structures however.

It is obvious from the foregoing considerations that erosion is a surface phenomenon. It is normally encountered in spillways, stilling basins, chutes, slabs and transverse joints, under water gates in regions where air entrainment is minimal if it exists at all, and on any irregular surface subjected to high water flow velocity.

Many repairing materials have been considered to remedy the effects of erosion. Those most frequently used for concrete surfaces are Gunite and a new type of heavily reinforced concrete slab [3-6]. These have been found quite effective in reducing but not completely eliminating erosion damage. However, the significant cost increases incurred have prompted users to seek alternatives. Recent laboratory experiments and field tests indicate that epoxy, epoxy mortars and concrete, polymer mortars and concrete, fibre-reinforced concrete and polymer-modified cementitious materials, etc. can be used successfully to repair the concrete surfaces of hydraulic structures. Some of these materials have properties that are superior to those of the conventional Gunite and steel plating and they are now commercially available, although in most cases the manufacturer's data are either negligible or insufficient for workers to perform specific repairs.

The purpose of this study was to determine the factors influencing the abrasion-erosion resistance of some mortars. The erosion test described forms part of a larger investigation to evaluate the efficiency of different mortars as repairing materials. The results reported here give only an indication of wear due to erosion based on the test data.

2. MATERIALS

A total of 28 different materials from nine manufacturers were investigated for the erosion test. Also included was a conventional cement mortar prepared in accordance with ASTM C109, which served as a reference. The materials fall into three main classes:

- epoxy-based mortars

- cement-based mortars or cementitious grouts

- polymer-modified cement-based mortars containing:
  - acrylics
  - styrene-butadiene rubbers (SBR)

It should be mentioned that for the epoxy mortars two particle sizes were used together: fine particles (Ottawa sand) and well-graded particles (Joliette sand from the Montreal area, as normally used by ready-mix concrete plants). For the cementitious grouts and polymer-modified mortars, most of the powders were premixed by the manufacturer, who provided no information on the exact ratio of the mix design. However, the cementitious grouts contained normal Portland cement, well-graded fine fillers, gassing and flowing agents while the powders for polymer-modified mortars contained normal Portland cement, well-graded fine fillers and some additives. In some cases, glass fibres were also added.

Tables 1a, 1b and 1c give details of the mix ratios of the epoxy mortars, cementitious grouts and polymer-modified cement-based mortars respectively. These materials were mixed and prepared according to the manufacturers' specifications and recommendations then cured for two days at room temperature and for 26 days in a curing box at 23 ±2°C and 50% R.H. The specimen dimensions were 2.54 cm x 7.62 cm x 1.27 cm.

3. EXPERIMENTAL

The erosion test was performed using a sand slurry and in-house developed apparatus (Figure 1), since no standard method exists in this field. The specimen holder can be rotated, allowing selection of the desired incidence angle. For this study, the angle was kept constant at 45°.

The slurry consisted of 20% wt. of 50/70 AFS silica sand in water; the volume used in the tank was about 7.4 litres. After impingement on the specimen, the slurry was collected in the tank, where it was recirculated through an air-powered double-diaphragm slurry pump. A calibration test showed that abrasive-sand particle degradation was negligible after 1 h. The mean velocity of the slurry was kept constant at 18.5 m/s for all the tests. In view of the slurry employed, it is reasonable to assume that the velocity of the abrasive particles is slightly less than that of the fluid. The velocity of the slurry was determined by using an electromagnetic flowmeter. Every 15 min, the specimens were wiped lightly, weighed and replaced in the same position. The total duration of a test for each specimen was 1 h.

Wear is expressed by the mass loss rather than the volume loss for several reasons. First, since most specimens were porous, they were kept immersed in water for 24 h prior to testing; hence their open pores were assumed to be filled with water from beginning to end of the test. Second, to be able to weigh dry specimens before a test, they must be dried after the test but, for the epoxy mortars, drying by heating results in degradation of the mortar. Third, because of the porosity, the densities of the specimens

were not easy to determine and, even if they were, could not be compared because of the variation in porosity from one product to the other. Nevertheless, in spite of the different materials tested, the high silica sand content of each mortar conducts at more or less similar densities from one specimen to another, so that the mass loss is justified as a wear measurement for comparison purposes. Two specimens of each type of mortar were tested and the wear result for each case corresponds to the mean mass loss.

4. RESULTS

The wear measurements taken at 15, 30, 45 and 60 min are plotted as a function of time in Figures 2a, 2b and 2c for the three classes of materials studied. After 15 min, the wear rates (corresponding to the slope of the straight lines) are constant, indicating that the mechanisms are the same during the test. In some cases, the straight lines do not pass through the origin.

The results for each specimen after 1 h of testing are reported in Table 2. To better distinguish between wear behaviors, the different materials were ranked as follows:

- materials exhibiting low wear values (L), i.e. mass losses from 0 to 0.5 g

- medium-wear materials (M), for mass losses from 0.5 to 1.0 g

- high-wear materials (H), corresponding to mass losses over 1 g. Inciden-

tally, in Table 2, some materials are categorized by time instead of mass loss because the wear value after that time was considered too high for further testing.

This ranking shows that in general epoxy mortars have lower mass losses (greater wear resistance) than grouts but that the latter are more wear-resistant than polymer mortars.

The eroded surfaces reveal that the slurry jet produces a hole nearly 1 cm wide. Two types of wear are observed in the centre of the hole: preferential wear of the cement, resulting in protruding particles (denoted by the letter C in Table 2), and wear of the two constituents of mortar (cement and sand particles) at the same rate but with no protruding particles (denoted by N). Polymer mortars and grouts tend to show wear type C and often high wear values, which is not the case for epoxy mortars. Figure 3 illustrates these two types of erosion wear on worn surfaces.

As the particle volume fraction was sufficiently high, the particles were in contact in all the mortars. The cement volume fraction in particular plays a role in the quantity of pores. Assuming that the particles are disposed in a compact arrangement, a higher cement content corresponds to a lower porosity, although even in impermeable mortars closed pores are present in small amounts. Table 2 gives a qualitative assessment of the porosity as suggested by optical microscope observation.

The erosion wear for each type of mortar is plotted in Figure 4 as a

function of its particle size. Different kinds of silica sand were mixed. The size distribution differed for each but it is possible, nevertheless, to identify at least two particle sizes for some kinds of sand. Since wear is not readily associated with any particular size, a horizontal bar is drawn on the graphs for large size distributions. For the epoxy mortars of the first group, wear seems to be independent of particle size in the range 0.3 to 0.7 mm. In the second group, the specimens were all prepared using the same kind of sand, different from the one used in the first group. The wear values of the second group are more or less the same but the average particle size is higher and, also, the porosity fraction.

For grouts, no clear relationship exists between wear and particle size, although the wear increases when particles are larger than 0.4 mm. Again, the particle size distributions were too large to be able to relate wear directly to particle size.

There are two types of polymer-modified cement mortars: the first type contained acrylics, the second type consisted of styrene butadiene rubber. The wear of the first type does not seem to follow a simple linear behavior but it is important to mention that the cement and the kind of particles present in these polymer mortars differ from one specimen to another. As for the second type, the wear shows a sharp decrease when the particle size increases from 0.4 to 2 mm. Comparison of the two groups at the same time yields no useful information on the wear/particle size relationship.

5. DISCUSSION

The erosion rates of the different mortars are fairly constant (Figure 2), notwithstanding the heterogeneity of the materials tested. For mortars corresponding to straight lines that do not pass through the origin, the erosion rate is higher at the beginning of the test. This variation may be due to modifications in the eroded-surface profile during the test: as the test proceeds, the angle between the eroded surface and the slurry jet decreases (Figure 5). It is well known that the erosion efficiency is higher at a normal incidence angle for brittle materials, with the result that any variation in the incidence angle during the test will significantly affect the erosion rate. The protective role of protruding particles on the eroded surface may also explain the decrease in the erosion rate after the incubation period. The length of the latter was not determined but it is controlled by the erosion of the cement until the protruding particles (of other materials) are able to protect the areas of cement already exposed. For the epoxy mortars, the wear resistance of the epoxy binder is high enough to be comparable to the wear resistance of the mortar particles, resulting in an eroded surface without preferential wear of the cement.

The observation of microstructures indicates that two types of pore are present in mortar samples: macropores and micropores. Macropores are due to the cement's difficulty in infiltrating between the mortar particles. Their size is of the same order of magnitude as the filler particles. The abrasive particles in the slurry are in the same size range (200-300 μm) so that when they impinge on the cement at the surface, the macropores are too large to be

associated with cement weakness at the surface of the material; hence the erosion rate is slightly influenced by the small amount of large pores.

Micropores, as their name implies, are much smaller in dimension and are located in the cement phase of grouts and polymer mortars. They are also smaller than abrasive particles and probably act as a weak bond, which increases erosion wear. The absence of such porosities in epoxy cement accounts for the toughness and high erosion resistance of epoxy mortars. Figure 6 illustrates the microstructures of a sample containing micropores and an epoxy mortar which is micropore-free.

These observations suggest that the erosion wear of the different mortars studied is due mainly to the degradation of the cement phase. The erosion of the particles of sand forming the mortars is considered negligible. The particles disbond from the eroded surface because of the wear of the surrounding cement. Considering that a mortar comprises two constituents with different erosion resistances, a relation between erosion wear and the ratio of abrasive particle size to mortar particle size is proposed.

First, the mortar is assumed to consist of a close-packed arrangement of erosion-resistant particles with the same granulometry. The surface area of the exposed cement is therefore equal to the particle dimension. Considering now the impingement of abrasive particles on the mortar, the erosion level will depend on the ratio of the abrasive particle size d_a to the mortar particle size d. Three ranges of abrasive particle size can be defined (see Figure 7):

1) $d_a \ll d$: high erosion level because the particles in the mortar do not protect the cement against small abrasive particles

2) $d_a \approx d$: low erosion level associated with good protection offered by protruding mortar particles

3) $d_a \gg d$: high erosion level, with the mortar being "seen" by the abrasive particles as a single-phase material (this range was not observed during the tests performed in this study).

Other factors might play an important role in the levels of the first and third ranges. For example, the first range can be affected by the fact that a particle size threshold exists under which no erosion occurs. The third range is also not easy to define because the damage caused by large abrasive particles is restricted to relatively small volumes; the macropores preventing the crack growth. In fact, in the third range, the mortar should be considered as a reinforced material.

The results for the epoxy mortars indicate that the particle sizes contained in the plateau correspond to the second range. Any increase in the amount of macroporosity and in the epoxy mortar particle size results in a higher wear level. It is difficult to interpret the results in cases where the mortar contains a large particle size distribution. This is especially true in the case of grouts, in particular for the polymer-modified mortar, because cement from a different manufacturer was used in each class. Grout particles are often larger than abrasive particles owing to the increase in

erosion wear with particle size, which corresponds to the first range of behavior.

The results obtained for the mortars containing glass fibres were not particularly good. If fibres improve the mortars' mechanical properties, their effect on erosion wear is insignificant. Because the erosion process is limited to the surface layer, the reinforcement brought about by glass fibres is ineffective. Liu and McDonald [7] report that fibre-reinforced concrete is less resistant to abrasion-type erosion than concrete without fibres, having the same type of aggregate and same water-cement ratio.

6. CONCLUSION

The different kinds of mortar tested are not easy to compare on a quantitative basis because of the numerous differences in their composition and water-cement ratios. Nevertheless, some qualitative characteristics serve to determine whether a mortar will have the required resistance to erosion by abrasion.

The first parameter is the presence of micropores in the cement itself. In most cases, the erosion process is governed by the erosion resistance of the cement. However this depends on the choice of the binder i.e. cement or epoxy. Epoxy mortar, for example, has no micropores to weaken the mortar and therefore has the best erosion resistance. Macropores that form between the sand particles do not seem to play an important role.

The size of particles contained in the mortar is also a determining parameter to consider in the evaluation of erosion resistance. Since the dimension of the exposed-cement region is directly proportional to the sand particle size, it is suggested to use mortar containing fine sand particles, which exhibit negligible erosion compared to cement particles. The sand surface fraction can be increased by using large sand particles. A mortar containing a wide distribution of particle size (or at least large and small particle sizes) will therefore offer the twofold advantage of good erosion resistance of the particle surface fraction and small exposed areas of the cement.

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TABLE 1a: DETAIL OF EPOXY MORTAR MIXES

Sample No.	Manufacturer	Resin/hardener (epoxy) ratio	Epoxy/filler ratio
21	M_2	4.63 : 1	1 : 3*
25	M_3	2 : 1	1 : 2*
35	M_2	2 : 1	1 : 3*
40	M_3	2 : 1	1 : 3*
51	M_9	2 : 1	1 : 1**
54	M_9	2 : 1	1 : 1**
57	M_9	2 : 1	1 : 3**
63	M_5	1 : 1	1 : 5**
68	M_5	2 : 1	1 : 6**
96	M_2	2 : 1	1 : 3**

* Ottawa sand
** Well-graded Joliette sand

TABLE 1b: DETAIL OF CEMENT-BASED MORTARS OR CEMENTITIOUS GROUTS

Sample No.	Manufacturer	Cement/sand ratio	Water/cement ratio	Water/grout ratio
1	M_1	*	--	0.14
30	M_2	*	--	0.14
31	Ref. Mortar	1 : 2.75	0.40	--
39	M_3	*	--	0.14
8	M_4	1 : 2	0.37	--

* Premixed by manufacturer

TABLE 1c: DETAIL OF POLYMER-MODIFIED CEMENT-BASED MORTARS

Sample No.	Manufacturer	Cement/sand ratio	Water/cement ratio	Latex/cement ratio	Water + latex/ cement ratio
58B	M_5	1 : 3	--	--	0.40
15	M_3	*	--	--	0.14
72B	M_6	*	--	--	0.19
79B	M_7	*	0.25	0.10	--
87B	M_2	*	0.15	0.10	--
89B	M_2	*	0.16	0.10	--
76B	M_4	1 : 2.5	--	--	0.30
83B	M_7	*	0.25	0.10	--
12	M_7	*	0.18	0.15	--
46	M_8	*	--	--	0.33
65	M_5	1 : 2.75	--	--	0.35
73	M_1	1 : 3	--	--	0.37
17	M_7	*	0.18	0.50	--

* Premixed by manufacturer

TABLE 2

Sample No.	Type of mortar (a)	Porosity (b)	Type of wear (c)	Wear	Class (d)
21	E	L	C	0.22 g	L
25	E	L	N	0.18 g	L
35	E	L	N	0.14 g	L
40	E	L	N	0.17 g	L
51	E	L	N	0.45 g	L
54	E	L	N	0.47 g	L-M
57	E	H	N	0.50 g	L-M
63	E	H	N	0.52 g	M
68	E	H	N	0.42 g	L
96	E	H	N	0.50 g	L-M
1	G	L	N	1.06 g	H
30	G	L	C	0.40 g	L
31	G	H	C	0.57 g	M
39	G	L	N	0.54 g	M
8	G+F	L	C	0.64 g	M
58B	P	L	C	15 min	H
15	P+A	L	C	0.71 g	M
72B	P+A	L	C	15 min	H
79B	P+A	L	C	0.93 g	M
87B	P+A	L	C	1.38 g	H
89B	P+A	L	C	15 min	H
76B	P+A+F	L	C	0.58 g	M
83B	P+A+F	L	C	1.29 g	H
12	P+R	L	C	0.57 g	M
46	P+R	L	C	30 min	H
65B	P+R	L	N	0.77 g	M
73B	P+R	L	C	1.10 g	H
17	P+R+F	L	C	0.48 g	L-M

(a) E: epoxy mortar, G: grouts, P: polymer mortar, A: acrylics, F: fibre glass, R: styrene-butadiene rubber.
(b) and (d) L: Low, M: Medium, H: High.
(c) C: Cement, N: No protruding particles.

LIST OF FIGURES

Figure 1: Erosion slurry apparatus for erosion resistance test.

Figure 2a: Erosion resistance of various epoxy mortars; average mass loss as a function of time. Specimen 31 is a standard reference cement mortar.

Figure 2b: Erosion resistance of various cementitious grouts; average mass loss as a function of time.

Figure 2c: Erosion resistance of various polymer modified cement based mortars containing SBR, co-polymers and acrylics; average mass loss of a function of time.

Figure 3: Microstructures of protruding particles (a) and no-protruding particles (b).

Figure 4: Erosion wear of epoxy mortars, grouts and polymer modified cement mortars as a function of their particle size.

Figure 5: Incident angle between eroded surface and slurry jet showing decrease in angle as erosion proceeds.

Figure 6: Microstructures of a sample containing micropores (a) and an epoxy mortar without micropores (b).

Figure 7: Ratio of abrasive particle size d_a to mortar particle size d and its effect on erosion level.

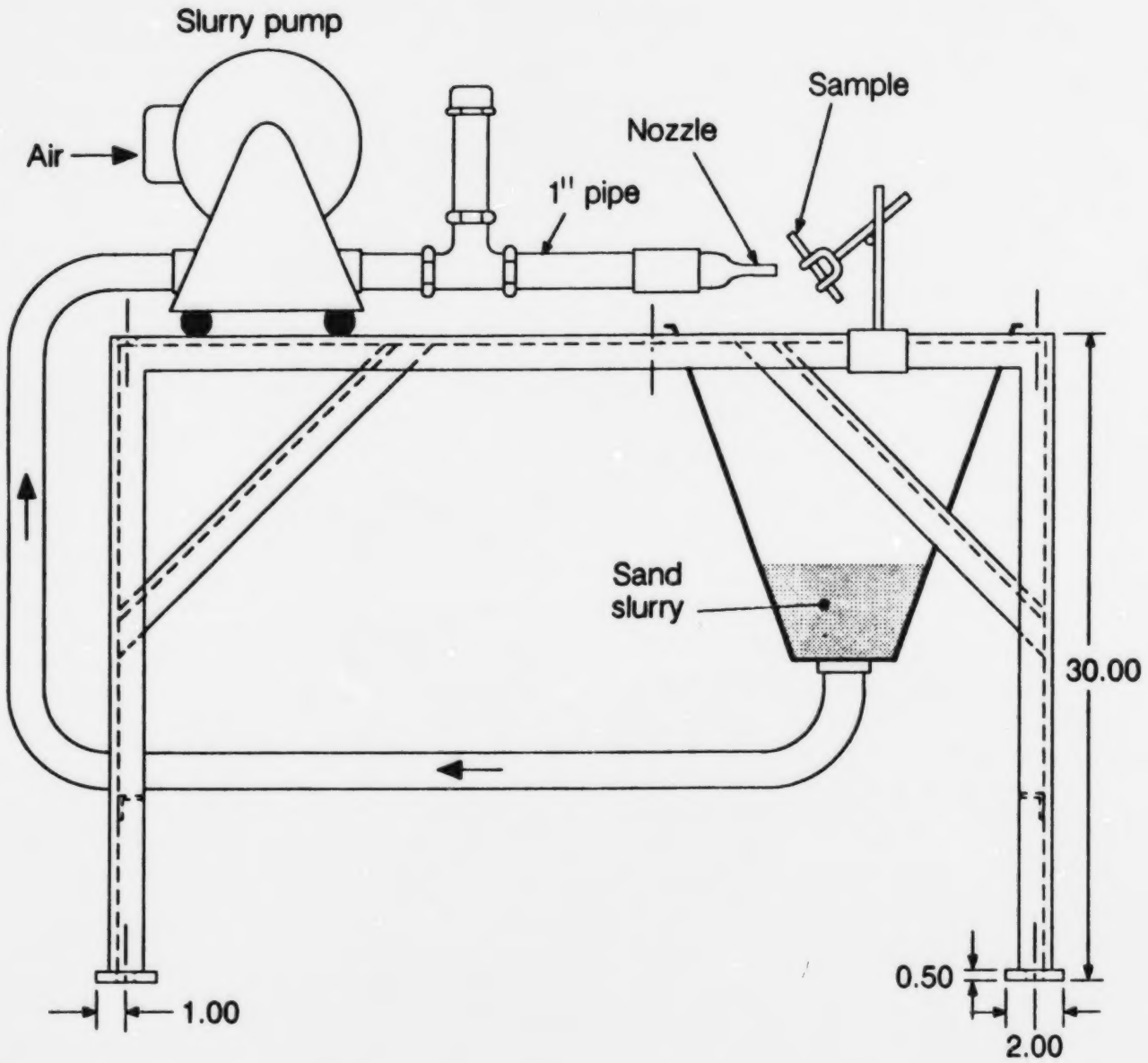


Figure 1: Erosion resistance apparatus with sand slurry made of 20% wt. of 50/70 AFS silica sand in water.

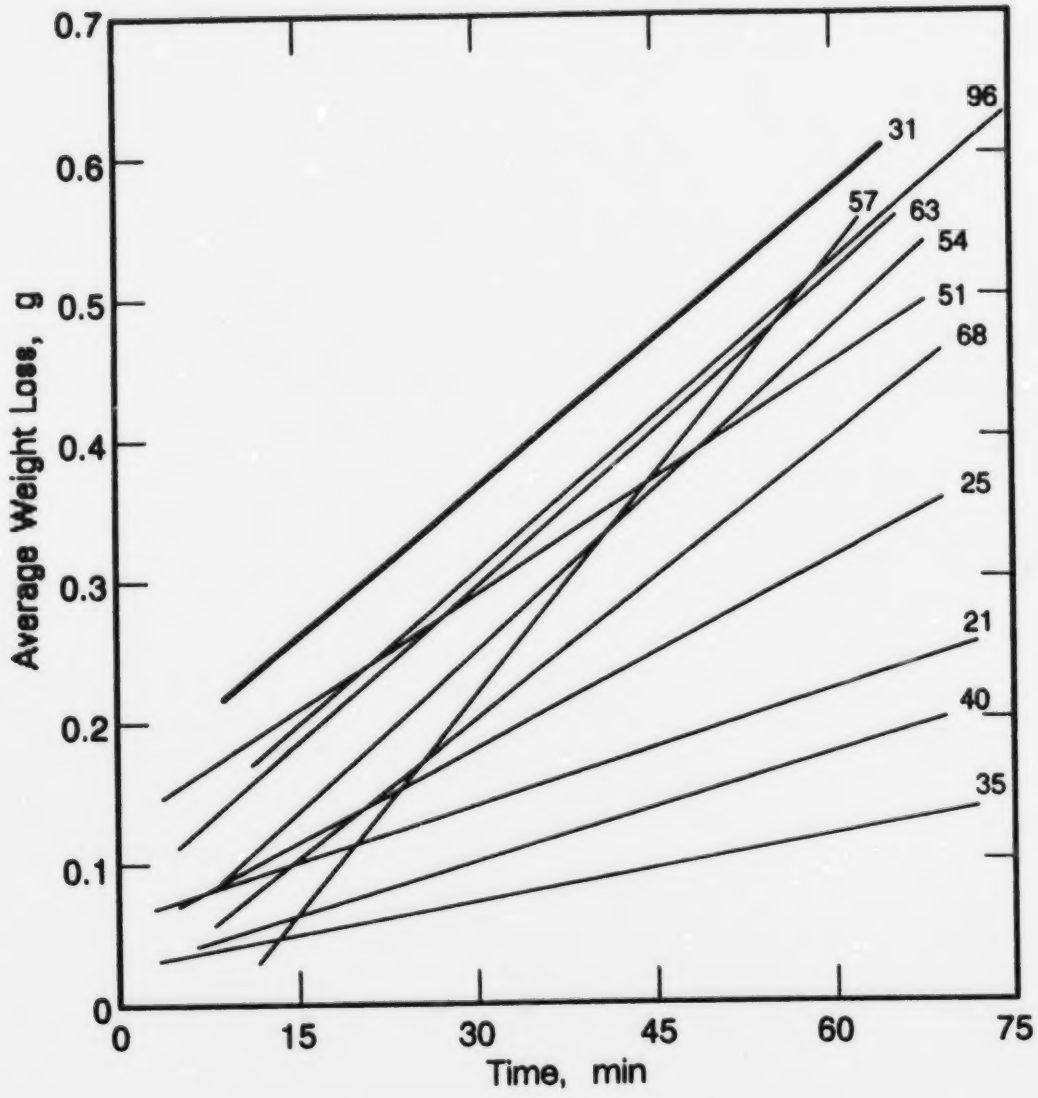


Figure 2a: Erosion resistance of various epoxy mortars; Average mass loss of each specimen as a function of time. Specimen 31 is a standard reference cement mortar.

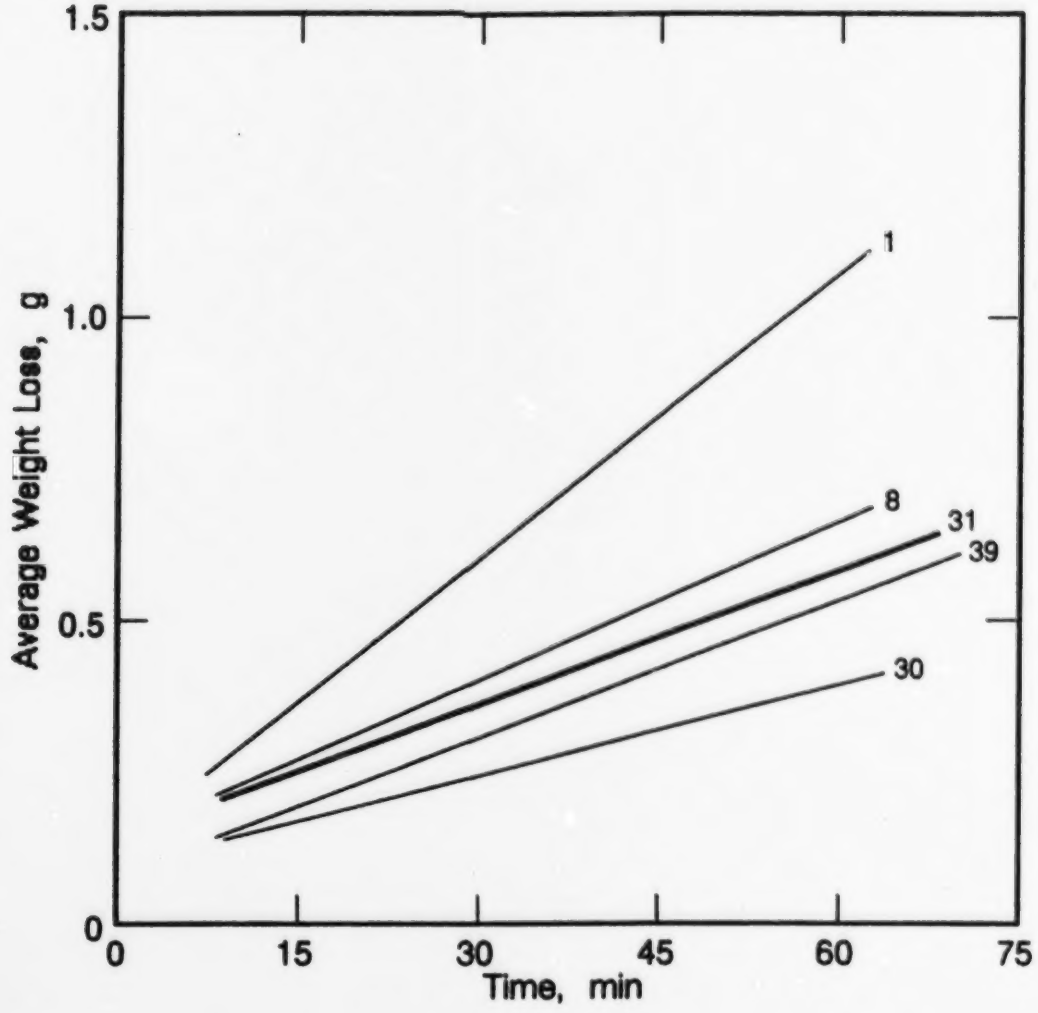


Figure 2b: Erosion resistance of various cementitious grouts; Average mass loss of each specimen as a function of time.

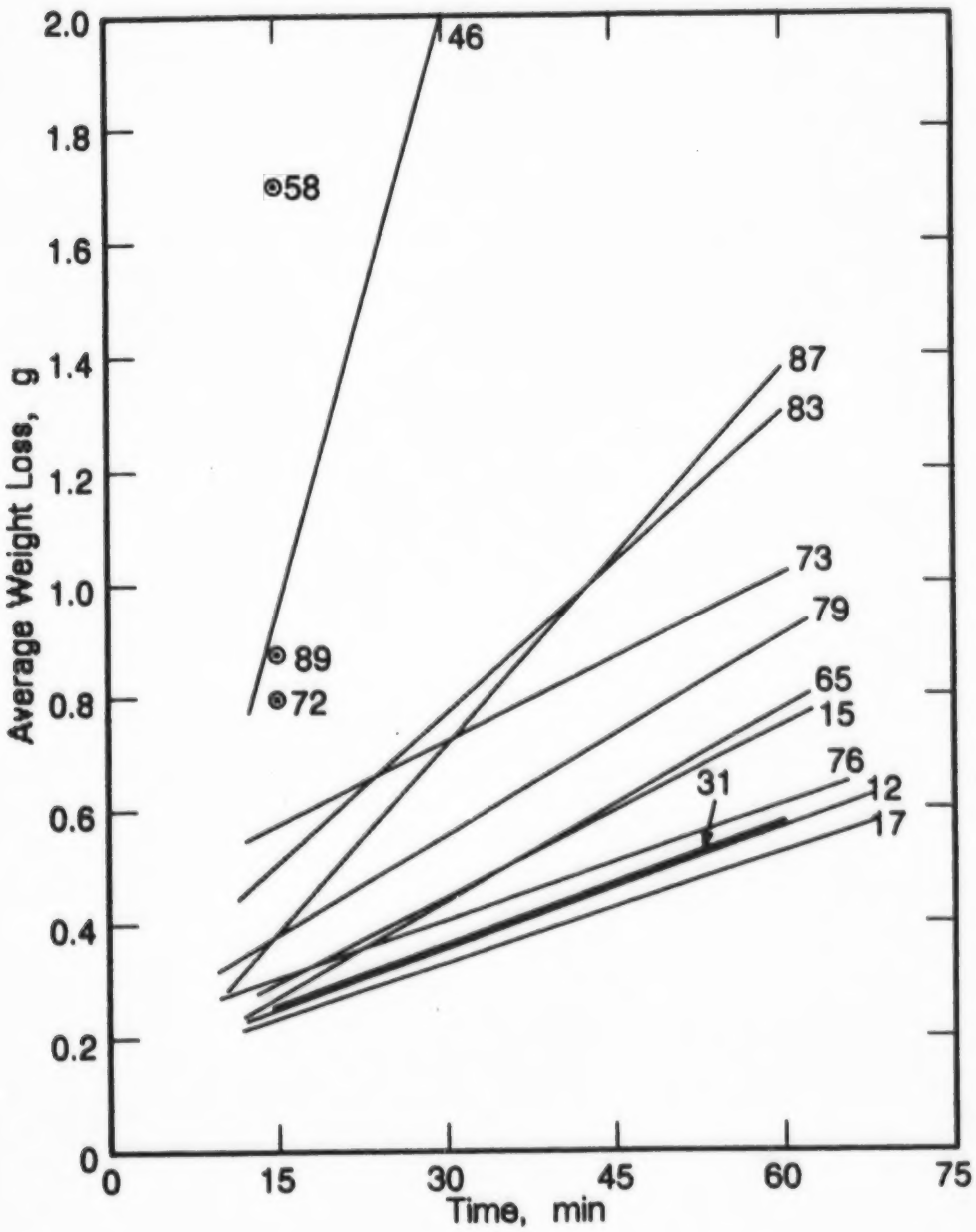
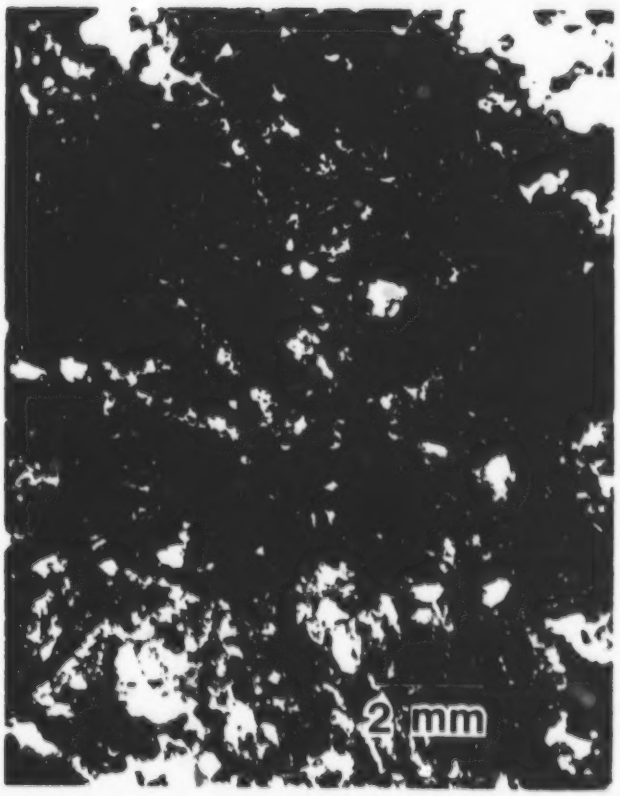
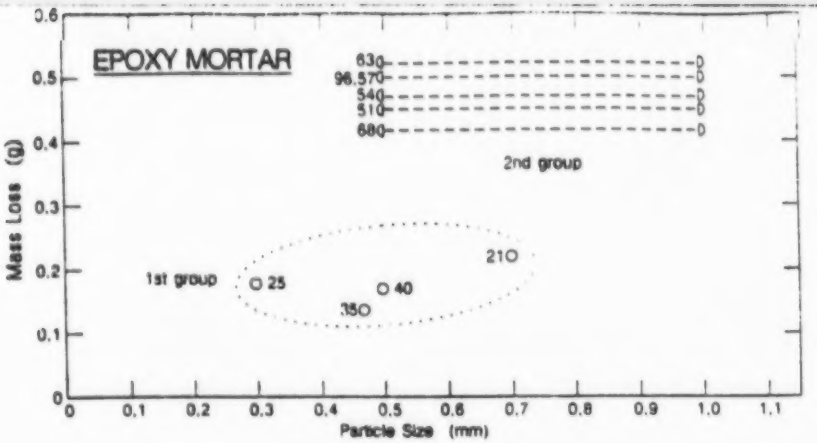


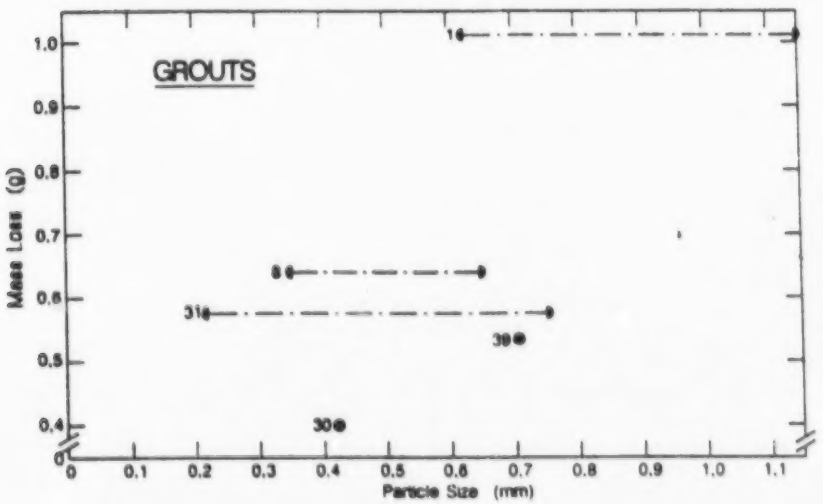
Figure 2c: Erosion resistance of various polymer modified cement mortars containing SBR, co-polymers and acrylics; Average mass loss of each specimen as a function of time. Specimen 31 is a reference cement mortar.

#798 fig 3-a



#57 fig 3-b


EPOXY MORTAR
630
96.570
540
510
680
2nd group
1st group
25
40
350
210
Mass Loss (g)
Particle Size (mm)


GROUTS
1
8
31
39
30
Mass Loss (g)
Particle Size (mm)

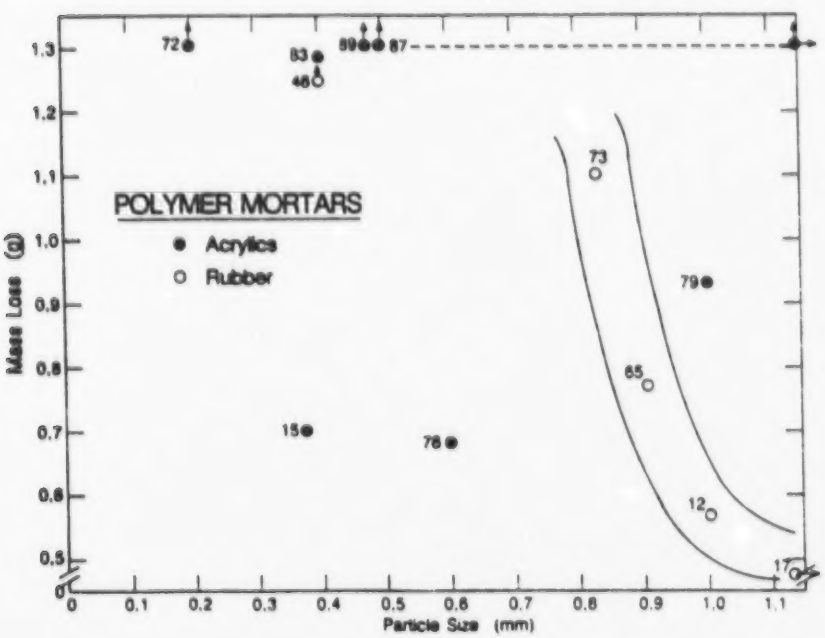
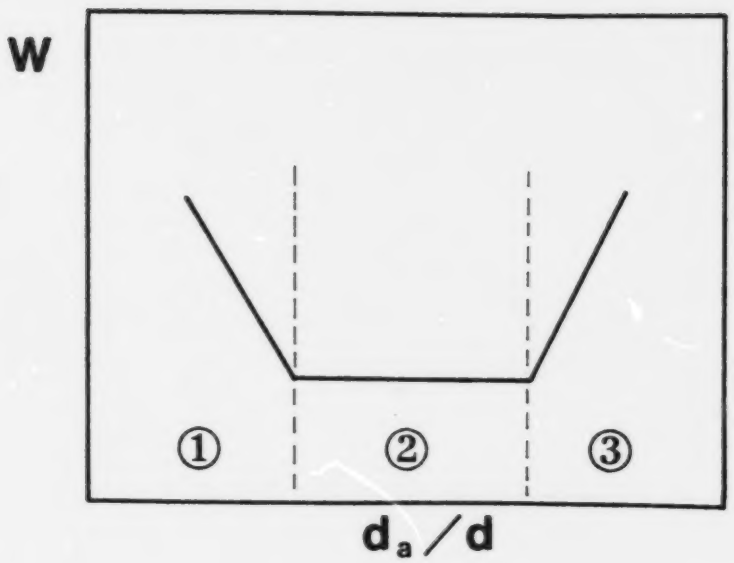

72
83
46
89
87
POLYMER MORTARS
Acrylics
Rubber
73
79
65
15
76
12
17
Mass Loss (g)
Particle Size (mm)

fig 5

fig 6-a #79B

fig 6-b #35


W
①
②
③
d_a / d